GEOFIZIKA VOL. 34 2017

DOI: 10.15233/gfz.2017.34.4
Original scientific paper
UDC 556.31

The temporal and spatial variations in groundwater salinity in Mazandaran Plain, Iran, during a long-term period of 26 years

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Received 14 June 2016, in final form 1 March 2017

Groundwater resources are one of the main sources of water supply for agricultural sector in Iran. Therefore, this study aimed to investigate the situation of groundwater salinity in Mazandaran for use in agriculture. In this study, statistical analysis of collected data, proper semivariogram model selection, cross validation of predictions and preparing probabilistic and zoning maps using geostatistical tools in the ArcGIS software, were performed. To investigate the spatial variations and preparing zoning maps of water salinity, ordinary kriging (*OK*) was used and the zoning maps were prepared. Spatial structure of electrical conductivity (*EC*) assessment showed a moderate spatial dependence in most years. Zoning and probabilistic maps of *EC* showed that the salinity of groundwater will be added and the most probable salinity is related the lowland areas in the eastern part of the plain. The use of this groundwater for irrigation in the long term can decrease the rice yield and faced rice production with a serious risk. The results of the Mann-Kendall and the Sen tests indicated a decreasing trend in the area of groundwater with *EC* higher than one dS/m in Mazandaran plain that this expressing an improvement in the quality of groundwater in the plain.

Keywords: ArcGIS, geostatistics, rice, trend

1. Introduction

The climate of Iran is typically classified as arid or semiarid. The country has an average annual precipitation of less than 250 mm. The average annual evaporation is 2,100 mm. Although about one percent of the world's population lives in Iran, the country shares only 0.36% of the world's total renewable water resources. Furthermore, the majority of annual precipitation falls during the non-growing season, and the spatial distribution of precipitation is highly uneven (Alizadeh 2010). In the context of water supply in Iran, groundwater withdrawal from aquifers has a priority over withdrawal from surface water. This is mainly because that the population of Iran and the demand for water are rapidly increasing and groundwater is available across all over the country. Presently, about 95% of the total fresh water withdrawal in Iran is used for agriculture; and it is estimated that about 80% of this water is extracted from groundwater (Ahmadi and Sedghamiz, 2008). Thus, investigating the spatial and temporal variations in groundwater quality parameters is required for effective management of aquifers, and to achieve sustainable agriculture.

Recognizing and evaluating spatial and temporal variations in groundwater quality parameters using deterministic methods may require a lot of fieldwork for collecting a large amount of data at different times and locations (Adhikary et al., 2010; Dash et al., 2010). Abundant development of computational tools and facilities e.g. ArcGIS, and the availability of geostatistical softwares (Nas and Berktay, 2010), have made it possible to assess the spatial and temporal variations in groundwater quality with a reasonable degree of precision.. Kriging is one of the most sophisticated geostatistical techniques which provides more accurate estimates for variables at unsampled locations (El-Fadel et al., 2014). Kriging is a best linear unbiased estimator (Delgado et al., 2010), and has a variety of different forms (Webster and Oliver, 2007). Ordinary kriging is the most common form widely used especially for generating spatial variability maps of random variables such as water quality parameters (Arslan, 2012; Nas and Berktay, 2010).

Delgado et al. (2010) used kriging to identify the quality of groundwater for agricultural uses within the state of Yucatán of Mexico. Chen and Feng (2013) investigated the temporal and spatial variations in the groundwater level and quality in Minqin oasis in northern China. Using the ordinary kriging, they generated the maps of spatial variability of groundwater depth and quality for different time periods and found that the groundwater in 76.2% of the area is not safe for potable uses. In a variety of studies, El-Fadel et al. (2014), Marko et al. (2014), Lahlou et al. (2013), Yimit et al. (2011), Dash et al. (2010), Adhikary et al. (2010), Nas and Berktay (2010), Al Kuisi et al. (2009), Nas (2009), Sun et al. (2009), Ahmadi and Sedghamiz (2008) and Hu et al. (2005) have employed geostatistical methods and the ordinary kriging for mapping groundwater levels and generating the maps of groundwater quality variables.

Indicator kriging method in which interpolation process is carried out based on indicator values is another kind of interpolation techniques in geostatistics. Jang et al. (2012) employed multivariate indicator kriging method for assessing the hydrochemical parameters of the groundwater used for irrigation in Pingtung Plain in Taiwan. The results showed that 54.4% of the groundwater is suitable for irrigation. Hu et al. (2005) used indicator kriging for assessing the groundwater quality and the risk of groundwater pollution by NO_3 in Quzhou County in the North China Plain. They discovered that *EC* in the most parts of the county is above 3 dS/m, and in the central parts of the county and at Henantuang town, groundwater is polluted by NO_3. Investigating the risk of groundwater contamination in Najafgarh Block, Delhi, India, Adhikary et al. (2010) used nonparametric indicator kriging and mapped the groundwater quality parameters. They reported that, in all parts of the study area, the values of *EC* and nitrate concentration is above the threshold, and the indicator kriging, by providing probability maps, is an effective tool in assessing the risk of groundwater contamination. In different studies, indicator kriging were used by Piccini et al. (2012), Dash et al. (2010), Al Kuisi et al. (2009), Flipo et al. (2007), Goovaerts et al. (2005) and Liu et al. (2004), to assess groundwater quality parameters, generate probability maps, and to delineate the vulnerable areas where groundwater is more exposed to contamination.

Investigating the trends in groundwater quality variations, and acquiring knowledge about whether water quality is improving, degrading, or remains constant over time are essential. The problem of detecting trends could be a complex issue (Kisi and Ay, 2014; Wahlin and Grimvall, 2010). Nowadays, nonparametric methods are commonly used by researchers for detecting trends. These methods are more reliable when the size of data set is small, some data are outliers or missed, or data are not normally distributed. Mann-Kendall method (Kendall, 1975; Mann, 1945) and Sen's slope estimator (Sen, 1968) are among the most widely used nonparametric methods for trend analysis. Using Sen's slope estimator and Mann-Kendall methods, and the data obtained from five hydrometric stations, Kisi and Ay (2014) assessed the trends in water quality parameters of Kizilirmak River in Turkey and compared the results achieved from the two methods. The results showed that the Sen's slope estimator is more appropriate than the Mann-Kendall method. Analyzing the trends in groundwater quality parameters in Swedish groundwater in a twenty-year period, Wahlin and Grimvall (2010) used the Mann-Kendall method and the data obtained from 77 piezometric stations, and found a decreasing trend in the concentration of solphate ion, and an increasing trend in acid-neutralizing capacity. Using Sen's slope estimator and Mann-Kendall method, Chang (2008), Panda et al. (2007), Bouza-Deaño et al. (2008), Yenilmez et al. (2011) and Tabari et al. (2011) investigated the trends in surface and groundwater quality and quantity parameters.

Ahmadpour et al. (2015) evaluated the correlation between Caspian Sea *EC* water and its distance from 63 sampled wells as compared with Sefidroud River *EC* water and its vertical distance from those wells. Sefidroud River is the biggest river in the north of Iran and irrigates 176 000 ha of paddy fields. The results showed that the correlation between Caspian Sea *EC* water and the wells distance was non-significant, whereas the correlation between Sefidroud River EC water and the wells distance was negative and significant, meaning that Sefidroud River *EC* affects on well water. Indeed in the previous decade, Sefidroud River *EC* water was doubled. Furthermore, Caspian Sea water level is on the decline after a 2.3 m increase during 1978 to 1995, so that its *EC* (about 22 dS/m according to Dordipour et al., 2004) cannot significantly affect on groundwater *EC*.

The present study aims to investigate and analyze the temporal and spatial variations in groundwater salinity in Mazandaran Plain, northern Iran. A trend analysis was also conducted. This topic was identified as being of importance to decision makers in providing them the necessary background to improve the groundwater management and the sustainability of rice production in the region.

2. Materials and methods

2.1. Characteristics of the study area

The present study was conducted in Mazandaran province which is located in northern Iran (Fig. 1). This province is bounded by the Caspian Sea to the north and Alborz Mountain Range to the south. Mazandaran province lies between 50° 21' and 54° 8' east longitude, and between 35° 46' and 36° 58' north latitude. This province covers a total area of 23756.4 square kilometers which accounts for 1.46% of the total area of Iran. At the census of 2011, the population of Mazandaran province numbered 3073943 persons, or about 4.1% of the population of the country.

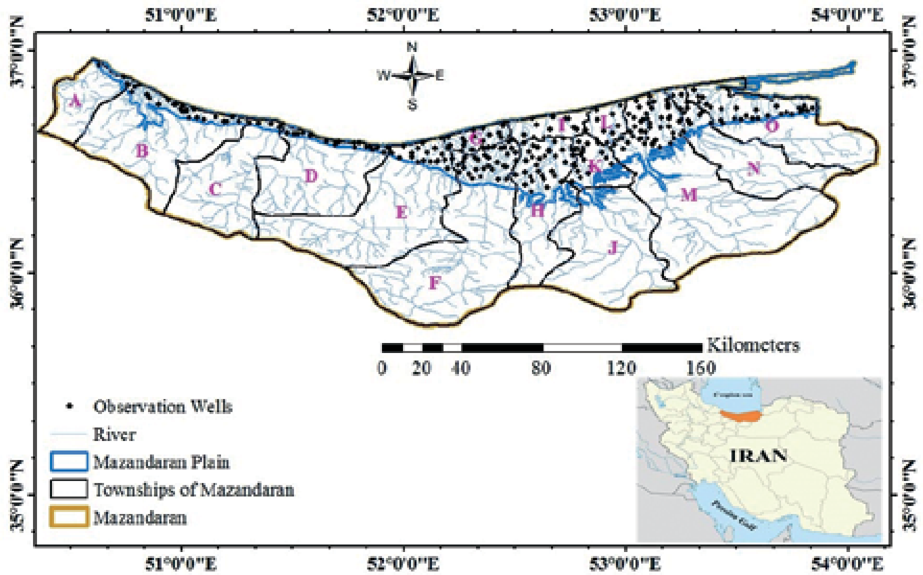

Figure 1. Location of the study area and position of sampling wells.

According to the Köppen-Geiger climate classification system (Kottek et al., 2006), the climate of Mazandaran province is humid subtropical or Cfa (C: temperate; f: without dry season; a: hot summer). With an average annual precipitation of 977 mm, Mazandaran is recognized as the second wettest province of Iran. The erosion of Alborz Mountain Range provided an abundant amount of sediment to the coastal plain of Mazandaran. This plain typically comprises three parts: two narrow parts in the east and west with a width of five to six kilometers, and a broad part in the middle with a width of 20 to 30 kilometers and an area of 3000 km^2. The formation and development of Mazandaran Plain was affected by different factors such as the quantity of water discharged by rivers, the area of river basins, the strength of rocks against erosion, and the large difference between the elevation of northern Alborz and the sea level elevation. Nearly in all parts of Mazandaran province, ground slope decreases from the mountainous terrains in the south to the plains near the Caspian Sea in the north. The texture of the soils in the province varies from heavy to very heavy and the main agricultural produce in the region is rice and citrus fruits. Caspian Sea, the biggest lake in the world, and its water level fluctuations impact on Mazandaran province climate. Figure 2 shows the Caspian Sea level fluctuations during 1922–2012.

2.2. Groundwater sampling

In this study, the salinity data from 277 observation wells scattered across the Mazandaran Plain were used. Data were collected by Mazandaran Regional Water Authority during the period of 1987–2013 in the month of May (in the growing season when the amount of precipitation is low). The UTM (Universal Transverse Mercator) coordinates of the observation wells were recorded using a

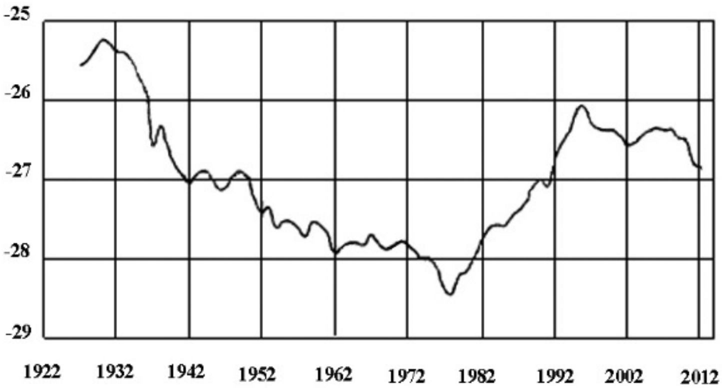

Figure 2. The Caspian Sea level (m, vertical axis) fluctuations graph during the years 1922–2012 (horizontal axis) for Anzali sea level measurement station (Qanqarmeh, 2012).

GPS (Global Positioning System) device. The geographical location of the study area and the position of the observation wells are presented in Fig. 1. In the present study, the groundwater salinity in unsampled locations were estimated using ordinary kriging; the maps showing the spatial variability of groundwater salinity, and the probability maps were generated for the month of May in each year using, respectively, the ordinary kriging and the indicator kriging. Maps were generated using the Geostatistical Analyst toolbox in ArcGIS 10.2 software package. Furthermore, analyzing the trends in salinity data over the years 1987–2013 was also conducted using Mann-Kendall method and Sen's slope estimator.

2.3. Data preparation

In the first stage, electrical conductivity (*EC*) data outside the range of $\bar{x} \pm \sum$ the average ± standard deviation times 3 were considered as outliers and eliminated from the data set. Then, descriptive statistics including maximum, minimum, mean, standard deviation, skewness, and kurtosis for the month of May in the years 1987 (the first year of the present study), 1994 (the year with the highest recorded salinity), 2005 (the year with the lowest recorded salinity), and 2013 (the last year of the present study) were calculated using the SPSS software. These values are presented in Tab. 1. As the kriging method has its best performance when data are normally or nearly normally distributed (Johnston et al. 2001), the Kolmogorov-Smirnov test of normality was conducted to check whether the distribution of data are normal. The results showed that data are not normally distributed, so data were normalized using an appropriate transfor mation.

2.4. Geostatistics analysis

The experimental semivariograms for the salinity data in each year were calculated and fitted by 11 theoretical models including circular, spherical, tetraspherical, pentaspherical, gaussian, rational quadratic, effect hole, K-Bessel, J-Bessel, and stables, and the best one was chosen for the estimation stage. The details of the theoretical models are presented in Johnston et al. (2001).

Table 1. Summary statistics of groundwater salinity data (EC in micromhos/cm) in the month of May.

Water Year	Min	Max	Mean	S.D.	Skewness	Coefficient of variation	Kurtosis	N
1987	441	6352	1611.13	1227.72	2.14	76.2	4.14	119
1994	320	5300	1309.95	874.00	1.97	66.7	4.63	189
2005	182	3360	944.99	461.07	1.34	48.8	3.46	216
2013	193	3190	1083.53	542.09	1.27	50.0	1.93	277

2.5. Ordinary kriging

In the present study, ordinary kriging interpolation technique was used to interpolate the salinity values and to create estimates for unsampled locations. A unique property of this technique is that the variance of the estimates is minimized, and the mean of errors is zero or almost zero (Goovaerts, 1997; Journel and Huijbregts, 1978).

2.6. Indicator kriging

In the present study, indicator kriging, a nonparametric geostatistical method, was used to construct the probability maps of groundwater salinity. In the indicator kriging method, the indicator values are coded one if the observed values of salinity are greater than the threshold ($EC > 1$ dS/m), and otherwise, the indicator values are coded 0. The details of this method are presented in Hu et al. (2005) and Delgado et al. (2010).

2.7. Cross validation

In the present study, five statistical error measures which are calculated by the geostatistical analyst toolbox in ArcGIS 10.2 were used for assessing the accuracy and precision of estimates. These error measures are mean error (*ME*), root mean square error (*RMSE*), average standard error (*ASE*), mean standardized error (*MSE*), and root mean square standardized error (*RMSSE*).

2.8. Mann-Kendall (MK) trend detection test

Regional trend analysis of groundwater quality parameters is a challenging task. In the present study, for detecting trends in groundwater salinity in the month of May from 1987 through 2013, Man-Kendall (*MK*) trend test was used. This method was first introduced by Mann (1945) and few years later Kendall (1975) expanded the method. The Man-Kendall trend test is commonly used for the analysis of monotonic trends in climatologic, hydrologic, and meteorological time series (Kisi and Ay, 2014).

2.9. Sen's slope estimator

Another nonparametric test for trend analysis which is common and widely used in hydrologic and meteorologic studies is the Sen's slope estimator. This method was first introduced by Theil (1992) and Sen (1968).

3. Results

3.1. Descriptive statistics

Groundwater salinity was investigated in Mazandaran Plain in a 26-year statistical period from 1987 to 2013 in this study. In the mentioned period, the best and the worst conditions of salinity were observed in 1994 and 2005 due to the presence of the maximum and the minimum saline area above one dS/m. The first and the last years of the study period were selected as 1987 and 2013, respectively. Summary statistics of groundwater salinity during these four years in May (the month of beginning rice cultivation in Mazandaran) is presented in Tab. 1. As shown in Tab. 1, the minimum *EC* as 182 micromhos/cm was observed in 2005 and the maximum *EC* was observed in the beginning of the study. The collected data are mostly scattered in 1987 and least scattered in 2005 compared to the mean. Results of skewness for all four years showed that the data were distributed asymmetrically with respect to mean. Since all coefficients of skewness were positive, distribution of the data was skewed right. Kurtosis values also showed that the data was scattered and not normally distributed. Thereby, data distribution was not normal based on values of standard deviation, mean, skewness and kurtosis. Normal data distribution is a prerequisite for proper performance and forecasting of ordinary kriging method. Thereby, the collected data were normalized prior to calculating semivariograms and plotting zoning maps.

3.2. Ordinary kriging

In order to study the spatial pattern of groundwater salinity in Mazandaran Plain using ordinary kriging, the best experimental semivariogram model of salinity was selected and fitted for each year among eleven different models. Accordingly, the best semivariogram model for groundwater salinity in 1987, 1994 and 2005 were exponential and the best semivariogram model for groundwater salinity in 2013 was gaussian. Delgado et al. (2010), Dash et al. (2010) and Yimit et al. (2011) studied spatial variations in qualitative properties of groundwater like *EC* using geostatistics, respectively, in Mexico, India and China. They showed that the best fitted semivariogram model is spherical. Adhikary et al. (2012) studied groundwater quality for drinking and irrigation purposes in Najafgarh in India. They found out that the best semivariogram model is exponential for all water quality parameters except chloride and hardness. Therefore, it can be stated that spatial patterns of electrical conductivity vary from one plain to another plain due to differences in climactic and soil properties of studied zones. Nugget-to-Sill ratio shows the strength of spatial structure of salinity. A ratio less than 0.25 represent a strong spatial dependence. A ratio from 0.25 to 0.75 represents a moderate spatial dependence. A ratio greater than 0.75 represents a weak spatial dependence (Dash et al., 2010). A strong spatial dependence of salinity in 1987, a moderate spatial dependence of salinity in 1994 and 2013 and a weak spatial dependence of salinity in 2005 were detected. The radius of the impact of groundwater salinity varies from 22 to 30 km.

The best experimental semivariogram model was selected. Estimating maps of groundwater salinity were plotted using ordinary kriging. Accuracy of zoning maps of salinity plotted using ordinary kriging technique was evaluated using cross validation. Value of mean standardized error was equal to zero in all these four years (mean standardized error was zero to one decimal point in 2005; however, this value was zero to two decimal points in other three years). The value of standardized root mean square error varied from 0.973 to 1.064, which can be considered as one. On the other hand, mean error was very small and close to zero for all these years. However, values of root mean square error and average standard error were high in 1987 and 1994, which may be due to inappropriate distribution and centralization of data in the study area and high amount of standard deviation and broad range of salinity in these two years. Minimum and maximum values and standard deviation were respectively as 441, 6352 and 1227.72 micromhos/cm in 1987. Minimum and maximum values and standard deviation were respectively as 320, 5300 and 874 micromhos/cm in 1994. Nevertheless, zoning maps of salinity plotted using ordinary kriging technique was acceptably and properly accurate.

Various studies were conducted on rice yield in different levels of salinity in northern Iran. The results showed that rice yield declined as salinity was measured more than one dS/m in irrigation water (Rice Research Institute of Iran). Paddy fields in this region are generally irrigated with water well. As a result, four classes of salinity consisting of 0–1 dS/m, 1–2 dS/m, 2–3 dS/m and > 3 dS/m respectively as areas without salt, areas with moderate salt, salty areas and very salty areas were used to show spatial variations in groundwater salinity in Mazandaran Plain in this study (Tab. 2).

Contents of Tab. 2 show that the areas with salinity level lower than one dS/m declined by 13% from the beginning of 1994 (the worst year in terms of salinity). Later, these areas increased by 32% by 2005 (the best year in terms of salinity). However, a downward trend was observed from 2005 to 2013, so that these areas decreased by 11% in 2013 compared to 2005. In addition, 74.9% of

Table 2. Percentage of the study area in each EC class (in micromhos/cm) for the month of May.

Year	0–1 dS/m	1–2 dS/m	2–3 dS/m	> 3 dS/m	EC > 1 dS/m	Condition
1987	32.9	55.2	5.5	6.5	67.1	First year
1994	20.3	74.9	4.8	0	79.7	Worstyear
2005	52.2	47.8	0	0	47.8	Best year
2013	41.3	58.7	0	0	58.7	Last year

Mazandaran Plain had moderate salinity in 1994 (the worst year in terms of salinity). However, a dramatic decrease was observed in areas with groundwater salinity more than 2 dS/m. Moreover, 2–3 dS/m salinity was no longer observed after 1994. In addition, more than three dS/m salinity was no longer measured after 1987.

Figures 3 to 6 show zoning maps of groundwater salinity in Mazandaran Plain in May using ordinary kriging method for the four years of 1987, 1994, 2005 and 2013.

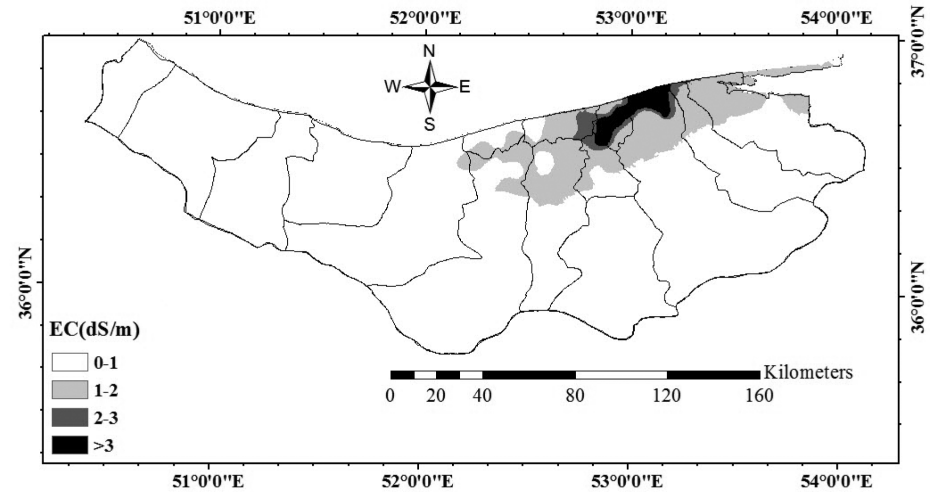

Figure 3. Zoning map using ordinary kriging in 1987.

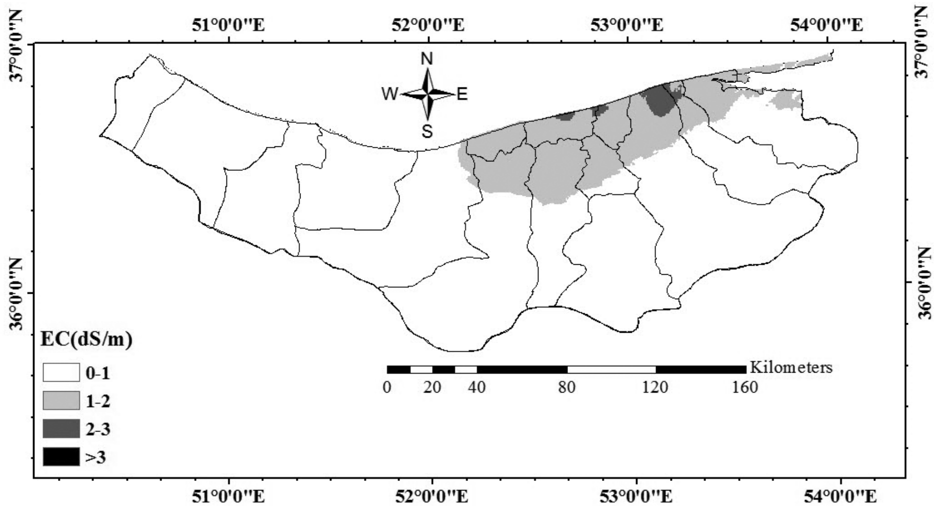

Figure 4. Zoning map using ordinary kriging in 1994.

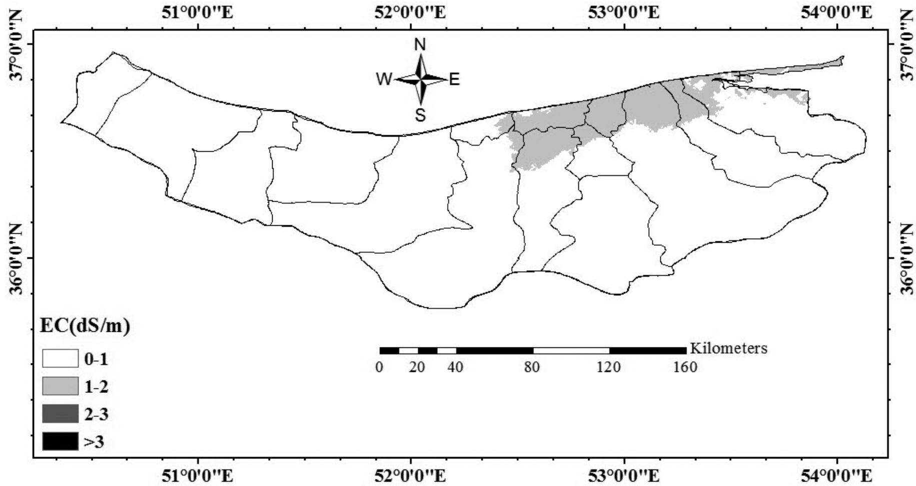

Figure 5. Zoning map using ordinary kriging in 2005.

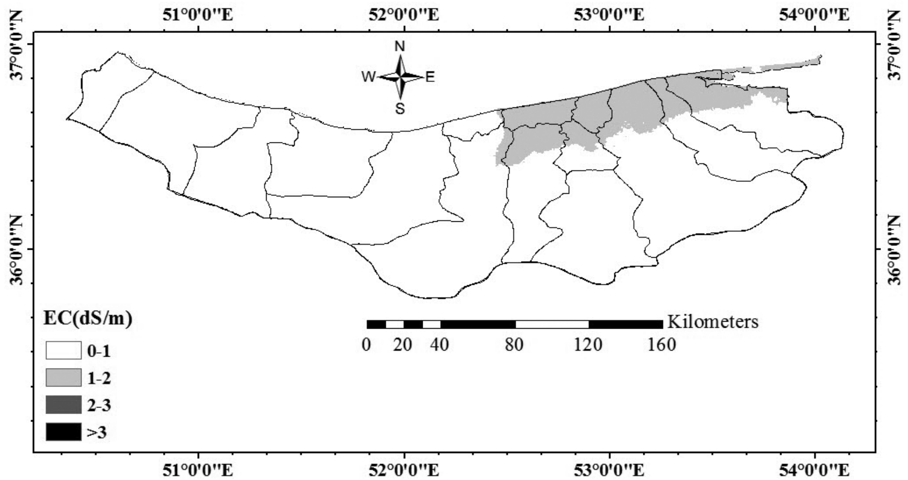

Figure 6. Zoning map using ordinary kriging in 2013.

3.3. Indicator kriging

In order to plot probabilistic maps of groundwater salinity using indicator kriging, the best experimental semivariogram model of salinity was selected and fitted for each year among eleven different models. Features of this model are presented in Tab. 3. Threshold value of groundwater salinity was intended as one dS/m due to decrease in rice yield. In this method, values above one dS/m were assigned as one and values less than one dS/m were assigned as zero. Stable was selected as the best semivariogram model for groundwater salinity in all four years. Contents of Tab. 2 show strong spatial dependence of groundwater salinity in 1994 and 2005, moderate spatial dependence in 2013 and weak spatial dependence in 1987. Radius of salinity impact varies from 12 km in 2005 to 30 km in 2013.

Accuracy of probabilistic maps of salinity using indicator kriging approach was evaluated using the cross-validation (Tab. 4).

Given that the mean error and standardized mean error values were close to zero, standardized root mean square value was close to one and *RMSE* varied from 0.4589 to 0.3875. It can be concluded that all probabilistic maps of salinity were properly and acceptably accurate.

Probabilistic maps of salinity were classified in four classes with a probability of 0 to 0.40, 0.40 to 0.80, 0.80 to 0.95 and 0.95 to 1. The results are presented in Tab. 5.

The results showed that 6% of Mazandaran Plain (290.5 km^2) had salinity level more than threshold value (one dS/m) with a probability more than 95% and 15% with a probability between 80% and 95% in 1987. The amount reached to 10.5% and 32% in the worst conditions in terms of salinity (1994). However, a downward trend was observed from 1994 to 2005 in groundwater salinity. Salinity level more than threshold value was observed in only 200 km^2 of Mazandaran with more than 80% probability in 2005. Decrease and increase in salinity may be due to advancement and recession of the Caspian seawater (Fig. 2). Despite recession of the Caspian Sea from 2005 to 2013, 23.6% of Mazandaran Plain (1147.7 km^2) had a salinity level more than one dS/m with a probability of

Table 3. Characteristics of semivariogram models (Indicator Kriging) – May.

Years	Models	Nugget (C_0)	Sill (C_0 + C)	Range (m)	Nugget ratio	Lag Size
1987	stable	0.1757664	0.186860	26,400	0.94	2200.0
1994	stable	0	0.179081	20,371	0	4000.0
2005	stable	0	0.239418	12,513	0	1486.5
2013	stable	0.1443294	0.222600	30,527	0.65	2600.0

Table 4. Cross-validation between measured and estimated values for groundwater salinity (IK) –May.

Year	Prediction errors				
	Mean	Root mean square	Average standard	Mean standardized	Root mean square standardized
1987	–0.0026	0.4355	0.4367	–0.0058	0.9965
1994	0.0003	0.3899	0.3541	0.0039	1.0712
2005	0.0049	0.4589	0.4526	0.0103	1.0164
2013	–0.0003	0.3875	0.4001	–0.0005	0.9732

Table 5. Probability ranges of areas exceeding groundwater salinity thresholds, by year (IK) in %.

Year	0–0.40	0.40–0.80	0.80–0.95	0.95–1.0	Condition
1987	26.17	52.92	14.94	5.97	First year
1994	23.73	33.48	32.28	10.52	Worst year
2005	48.42	47.35	4.12	0.11	Best year
2013	31.34	37.65	23.60	7.41	Last year

80 to 95%. In addition, 7.4% of Mazandaran Plain (360.6 km^2) had a salinity level more than one dS/m with a high probability more than 95% of salinity dS/m. This shows decreased rice yield with a probability higher than 80% in 2013 in 31% of Mazandaran Plain.

Figures 7 to 10 show probabilistic maps of groundwater salinity in Mazandaran Plain in May using indicator kriging approach for four years of 1987, 1994, 2005 and 2013. Figures 7 and 10 show that the probability that groundwater salinity would be more than one dS/m in Mazandaran Plain increases from the west to the east and from the south to the north. Thereby, salinity level would be above threshold value and in rice yield in eastern half of the plain would decline with almost 100% probability. This probability decreases in western half of Mazandaran. In addition, probability of more than 80% salinity level in 2005 (Best year in terms of salinity) is close to zero. However, there is high possibility of more than 80% salinity in 1994 (the worst year in terms of salinity) in the eastern part of Mazandaran Plain.

Figure 11 shows temporal changes in groundwater salinity. As it can be seen, the surface area with EC lower than 1 dS/m has increased during the study

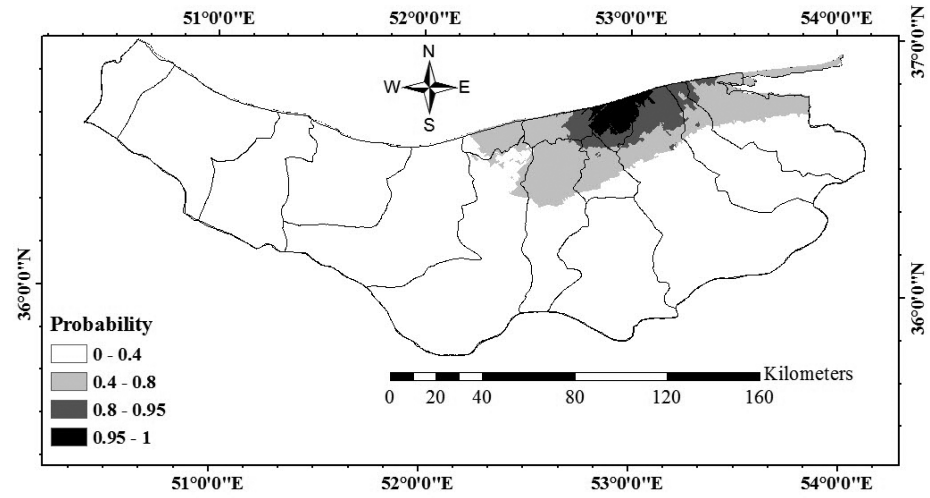

Figure 7. Zoning map using indicator kriging in 1987.

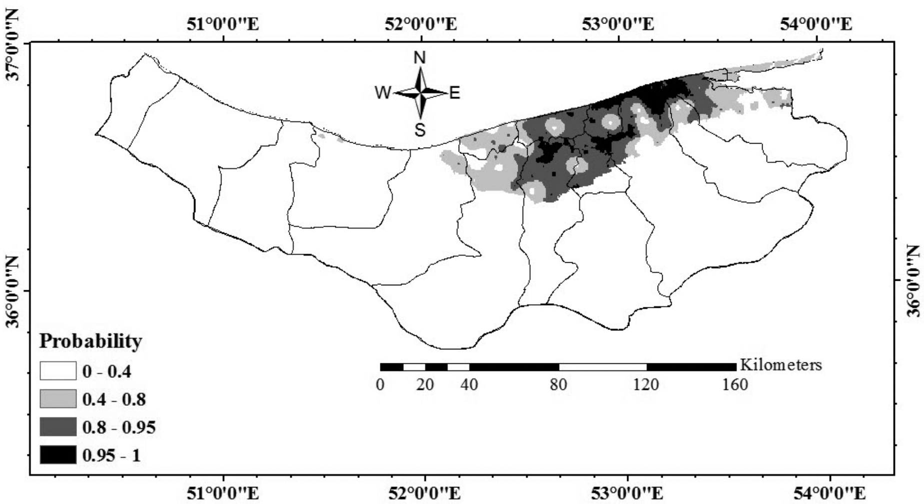

Figure 8. Zoning map using indicator kriging in 1994.

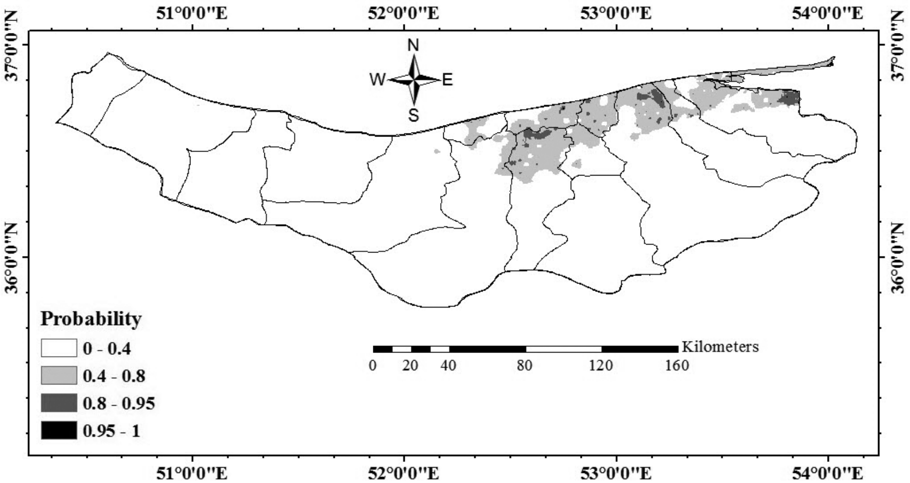

Figure 9. Zoning map using indicator kriging in 2005.

period, whereas the surface area with other *EC* classes (1–2, 2–3 and higher than 3 dS/m) has decreased in the same period. One should have an idea from spatial distribution of statistical parameters to measure error. Due to lack of space just two examples were prepared in 2013. Figure 12 shows the spatial distribution of prediction standard error for ordinary kriging as well as Fig. 13 shows the spatial distribution of prediction standard error for indicator kriging. In both figures, the prediction standard error is low for the most part of the area except of a small area in the northeastern part of the plain.

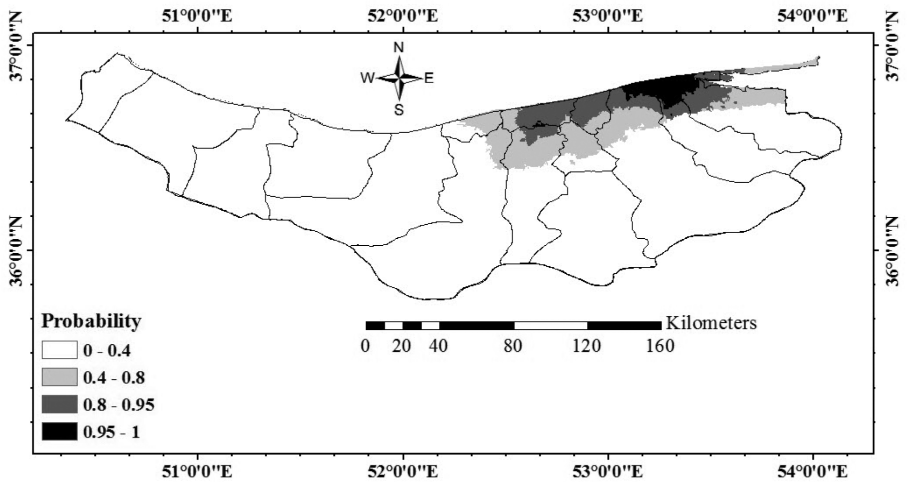

Figure 10. Zoning map using indicator kriging in 2013.

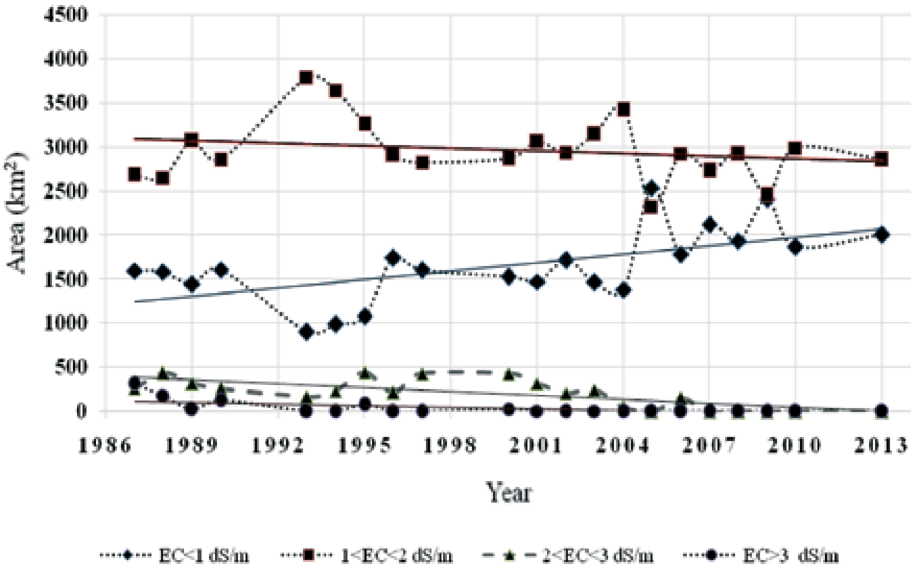

Figure 11. Temporal changes in surface area for each class of groundwater EC during 1987–2013.

Table 6 shows the results of Mann-Kendall and Sen estimator for groundwater salinity parameter in Mazandaran Plain. Mann-Kendall test results showed a significant and positive trend for 0–1 dS/m salinity at 1% level, a significant and negative for 2–3 dS/m and > 3 dS/m and 1 dS/m salinity, respectively, in 5%, 1% and 0.1% levels and no trends for 1–2 dS/m. Given the negative trend for > 1 dS/m salinity and the positive trend for < 1 dS/m salinity, groundwater

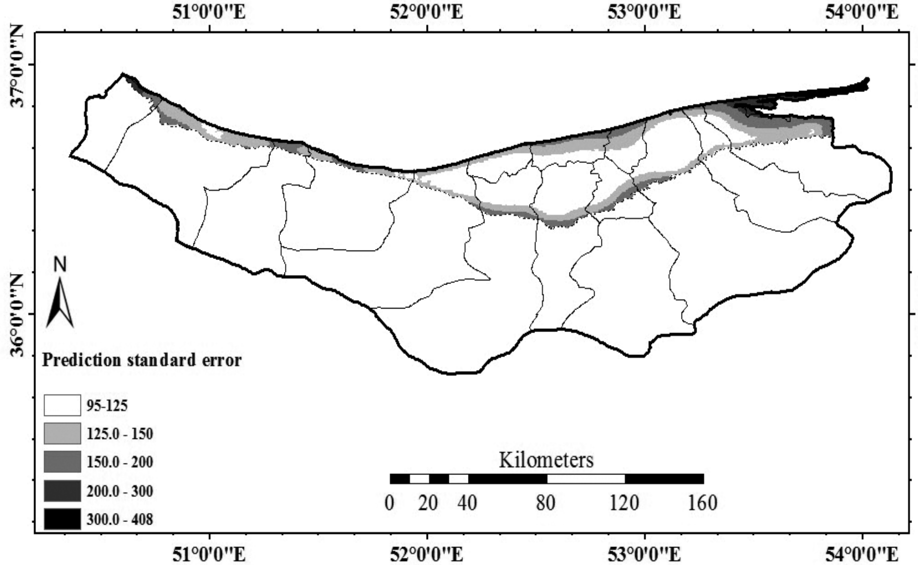

Figure 12. Spatial distribution of prediction standard error for ordinary kriging method in 2013.

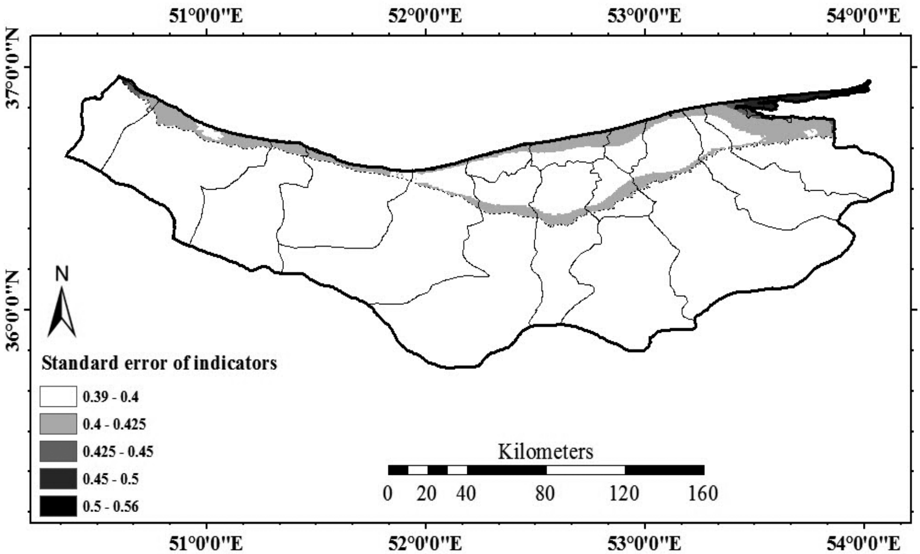

Figure 13. Spatial distribution of prediction standard error for indicator kriging method in 2013.

quality has improved in Mazandaran Plain over the course of 1987–2013. The results of Sen's slope estimator are shown in Tab. 6 in which Q represent slope and B shows a constant in the equation of Sen's slope estimator. A maximum slope was observed in less than one dS/m salinity and a minimum salinity was observed in > 3 dS/m salinity.

Table 6: The results of Man-Kendall and Sen method in analyzing the trend of groundwater salinity fluctuations in Mazandaran Plain (1987–2013) in the month of May.

Parameters	Mann-Kendall trend		Sen's slope estimate	
	Test *Z*	Signific.	*Q*	*B*
EC 0–1 dS/m	2.75	**	424.533	15225.73
EC 1–2 dS/m	–0.63	ns	–111.311	35413.22
EC 2–3 dS/m	–3.90	***	–212.203	4031.86
EC >3 dS/m	–3.30	***	–13.881	235.98
EC >1 dS/m	–2.75	**	–424.533	41271.27
Equation Sen's slope estimator	f (year) = Q × (year – firstDataYear) + B			
ns, *, **, and *** presents, respectively, no significant correlation, and significant correlation at significance levels 5, 1, and 0.1%				

4. Discussion and conclusion

In this study, spatial and temporal variations in groundwater salinity were examined in Mazandaran Province in Iran in a 26-year period from 1987 to May 2013 (the beginning of the agricultural season and rice cultivation). In this paper, the results of four years of 1987, 1994, 2005 and 2013 respectively as the beginning of study, the worst conditions in terms of salinity, the best conditions in terms of salinity and the end of the study were presented. For this purpose, non-parametric ordinary kriging and indicator kriging methods were respectively used to plot zoning maps and calculate salinity probabilities. Geostatistical analysis of the data was performed using the Geostatistical Analyst toolbox in ArcGIS10.2. Exponential model was used for spatial structure of salinity in ordinary kriging method in 1987, 1994 and 2005 and Gaussian model was used in 2013. Stable model was used in indicator kriging approach. Geostatistical analysis showed that groundwater salinity in ordinary kriging method had a strong spatial dependence in 1987, a moderate spatial dependence in 1994 and 2013 and a weak spatial dependence in 2005. Geostatistical analysis in indicator kriging approach showed a strong spatial dependence in 1994 and 2005, a moderate spatial dependence in 2013 and a weak spatial dependence in 1987.

In this study, the difference in semivariogram results in different years may be due to various climatic conditions such as temperature and rainfall, non-uniform sampling points, drainage, land use change and water level changes in the Caspian Sea as well as advancement or recession of the seawater (Arslan, 2012).

Accuracy of zoning maps and probability of salinity were evaluated using the cross-validation. The results showed that all the probability and zoning maps were acceptably and properly accurate. The zoning and probability maps suggested that the amount of groundwater salinity generally increased from the west to the east and from the south to the north toward slope of the ground in Mazandaran. The maximum probability of salinity was observed in the eastern region in the lowest areas of the plain near the sea. This indicates high probability of decrease in rice yield in half of the eastern parts of Mazandaran Plain. Minimal probability of salinity was also observed in western areas of the plain.

Maximum salinity was observed in east of the plain in lowest areas of Mazandaran near the sea. This could be due to a variety of reasons such as increased area of cultivated land in the east and center of Mazandaran compared to the west of Mazandaran, which led to flowing of drainage water to groundwater sources, high concentration of population and excessive removal of groundwater resources in the region as well as low elevation of this area compared to other areas in Mazandaran. This caused leaching of salts in farms and upland areas and accumulation of salts in these areas, which resulted in salinization of water and soil in this area. Existence of Miankaleh wetlands in this area and advancement of sea water into fresh water aquifers lead to formation of this type of aquifer in this region. Therefore, management and exploitation of groundwater in this area requires special attention and is considerably important.

Changes in groundwater salinity in Mazandaran Plain can be caused by changes in water level of the Caspian Sea due to increased temperature and decreased rainfall in the region as well as increased water level and advancement of the seawater in Caspian Sea until 1994 and recession of the seawater after 1994. Since recession of the seawater was evident after the 2005, a decrease was observed in areas with 1–2 dS salinity. This may be due to excessive exploitation of groundwater resources and overuse of chemical fertilizer.

Variations in groundwater salinity in Mazandaran Plain were assessed using Mann-Kendall test. In addition, the slope of the trend line for all the data series was determined using Sen's estimator. The results showed a significant and positive trend for 0–1 dS/m salinity in 1% level and a significant and negative trend in 2–3 dS/m, > 3 dS/m and 1 dS/m salinity in respectively 5%, 1% and 0.1% levels. The most severe negative trend was observed in 2–3 dS/m salinity (z-statistic = –3.90). Mann-Kendall test results and Sen's slope estimator indicated improvement in the quality of groundwater in term of salinity from 1987 to 2013.

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SAŽETAK

Vremenske i prostorne varijacije salaniteta podzemnih voda u ravnici Mazandaran, Iran, tijekom dugogodišnjeg razdoblja od 26 godina

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Resursi podzemnih voda jedan su od glavnih izvora vodoopskrbe poljoprivrednog sektora u Iranu. Stoga je ova studija usmjerena na istraživanje stanja saliniteta podzemnih voda u Mazandaranu koje se koriste u poljoprivredi. U ovoj studiji provedena je: statistička analiza prikupljenih podataka, odabir pravilnog modela semivariograma, unakrsno potvrđivanje predviđanja i pripremanje probabilističkih i zoniranje karata koristeći geostatističke alate u ArcGIS softveru. Da bi se istražile prostorne varijacije i pripremile karte slanosti vode korišteno je obično krigiranje (*OK*) i pripremljene su karte zoniranja. Prostorna struktura procjene električne provodljivosti (*EC*) pokazala je umjerenu prostornu ovisnost u većini godina. Zoniranje i probabilističke karte električne vodljivosti pokazale su da će se dodati slanost podzemnih voda, a najvjerojatnija slanost povezana je s nizinskim područjima u istočnom dijelu ravnice. Korištenje takvih podzemnih voda za navodnjavanje dugoročno može smanjiti prinos riže i proizvodnju s rižom s ozbiljnim rizikom. Rezultati ispitivanja pomoću Mann-Kendall-ovog i Senovog testa ukazali su na trend pada podzemnih voda s električnom vodljivošću > 1 dS/m, što upućuje na poboljšanje kvalitete podzemnih voda u ravnici Mazandaran.

Ključne riječi: ArcGIS, geostatistika, riža, trend

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